APPENDIX M

CAP DESIGN AND CONSTRUCTION EVALUATION

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M.1 INTRODUCTION

This document addresses the cap system under consideration for portions of the Upper Reach of the Housatonic River and the erosion protection system for the riverbed. Specifically, the selection of cap and erosion protection materials are discussed and evaluated. A conceptual design is also developed in accordance with EPA recommendations and guidelines in order to estimate the materials and quantities that may be needed to install a cap/armor system. This document addresses the design issues for both installation of a sorptive layer in the banks and in the riverbed, as well as providing an initial design basis for the selection of armor stone in riverbank and riverbed areas. The conceptual design developed here is intended only for use in conducting the EE/CA. Should capping be implemented as part of the removal action on the EE/CA Reach a detailed design analysis must be made. The erosion protection layer will be required for the riverbed and lower riverbanks. A stone armor is sized for the EE/CA; however, the actual erosion protection layer material may change with detailed design analysis.

M.2 BACKGROUND

The use of in situ caps (ISCs) for the containment of contaminated sediments is well documented. One comprehensive reference is the U.S. EPA technical document entitled *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* prepared under the Assessment and Remediation of Contaminated Sediments (ARCS) Program (Palermo, et al., 99-0224). The document addresses the purpose and functions of an ISC, the components of an ISC, and issues related to the design of an effective ISC.

As stated in the above-referenced document, an ISC serves three functions:

a) Physical isolation of the contaminated sediment from the benthic environment.
b) Stabilization of contaminated sediments, preventing resuspension and transport to other sites.
c) Reduction of the flux of dissolved contaminants from groundwater and sediment into the river.

In order to serve these functions, various materials have been used to construct ISCs including armor stone, gravel, sandy soils, geomembranes, and geotextiles. Depending on site conditions, the cap may be composed of a single component or a combination of components to form a composite ISC. The thickness of an ISC also varies and is determined by site conditions such as anticipated future use, potential for erosion, current or anticipated aquatic life, hydraulic conditions (i.e., groundwater flow), and construction considerations.

The EPA guidance document enumerates several general steps for the design of ISCs for a variety of sites. These include:

a) Identifying candidate capping materials and compatibility with contaminated sediment at the site.
b) Assessing the bioturbation potential of indigenous benthos and designing a cap component to physically isolate sediment contaminants from the benthic environment.
c) Evaluating potential erosion at the capping site due to currents, waves, and propeller wash, and designing a cap component to stabilize the contaminated sediments and other cap components.
d) Evaluating the potential flux of sediment contaminants and designing a cap component to reduce the flux of dissolved contaminants into the water column.
e) Evaluating potential interactions and compatibility among cap components, including consolidation of compressible materials.
f) Evaluating operational considerations and determining restrictions or additional protective measures (e.g., institutional controls) needed to ensure cap integrity.

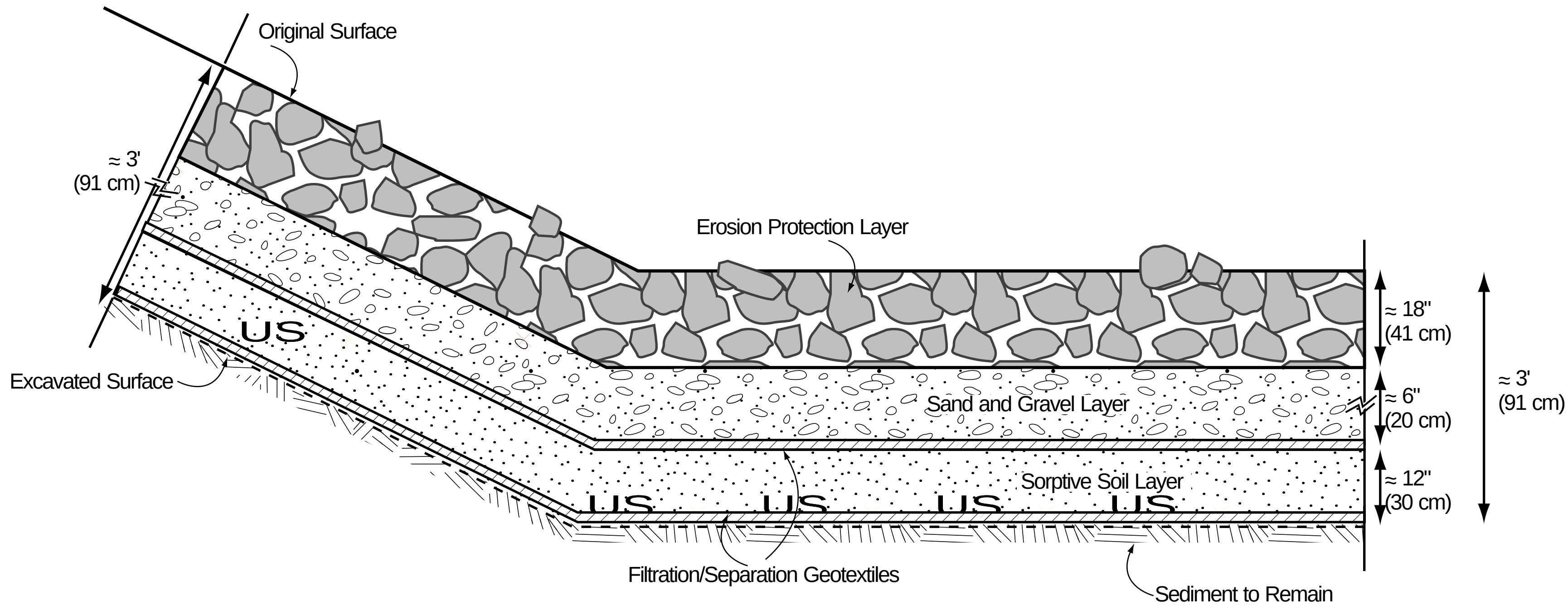
M.3 DESIGN CONSIDERATIONS

The following text addresses each of the general design steps listed above.

***Identify candidate capping materials and compatibility with contaminated sediment at the site*.**

The proposed materials for the ISC for the Upper Reach of the Housatonic River are erosion protection materials (cobbles, riprap, articulated concrete block segments, gravel, and sandy soil), silty sandy soil with a specified carbon content, and geotextiles. A typical cap cross section proposed for this site is presented in Figure M-1. As shown in this figure, the cap is composed of three distinct components:

Sorptive Soil Layer. The sorptive soil, composed of a silty sandy soil with a specified carbon content (either naturally occurring or manufactured soil), placed to a thickness of 6 to 12 inches will act as an absorbing layer to "hold" contamination. The sorptive soil is anticipated to have an organic content of no less than 0.5%, measured as total organic content (TOC). The material will provide the primary means of contaminant isolation to reduce the potential for PCBs to migrate from underlying sediments or soils upward through the riverbed or lower banks and into the water column. There are no analytical data on riverbank soil PCB concentrations at depths greater than 3 ft. However, based on the concentrations observed in the 2- to 3-ft-depth interval in the banks, PCB concentrations below the 3-ft depth in the banks may be elevated. In the lower bank areas of all subreaches there exists the potential for transport of PCBs from underlying contaminated soils into the clean backfill due to groundwater flow from the contaminated soil, through the clean backfill, and into the river and riverbed sediments. As a result it may be appropriate to install a sorptive soil layer (silty sand with a minimum TOC of 0.5%) as part of the backfilling and reconstruction of the lower bank areas. This layer would extend approximately 6 ft (vertical) above the average daily water level in all subreaches.



LEGEND

- Erosion Protection Material
- Sand and Gravel
- Sorptive Soil
- Sediment
- Geotextile

ENGINEERING EVALUATION/COST ANALYSIS
Upper Reach of the Housatonic River
Pittsfield, Massachusetts

FIGURE M-1
TYPICAL CAP CROSS SECTION

99P-2944a

It may be necessary as part of the EE/CA remedial design to gather additional PCB data at depth in the lower bank areas to support modeling of PCB transport and confirmation of an appropriate sorptive layer thickness.

The sorptive soil will be encapsulated between two geotextiles. The geotextile “sandwich” will provide for stability of the sorptive soil by minimizing the potential for dispersion and segregation into adjacent layers within the cap. The lower geotextile will minimize upward movement of sediment particles and will segregate the sorptive soil from the underlying sediment. Similarly, the upper geotextile will both contain the sorptive soil while separating it from the overlying sand and gravel layer.

Sand and Gravel Layer. The sand and gravel layer is composed of predominantly granular material up to a maximum particle size of about 3 inches. The sand and gravel will be placed to a thickness of between 6 and 8 inches and will act as a cushioning layer between the underlying geotextile and the overlying erosion protection layer.

Erosion Protection Layer. The erosion protection layer is intended to provide protection for the sand and gravel layer and the underlying sorptive soil and geotextile from the forces of erosion, debris impact, and ice flow. In areas of the riverbed where potential high-flow conditions may require installation of armor stone to prevent excessive erosion, the erosion protection layer will be constructed from cobbles or riprap up to about 12 inches in diameter. The material will be placed to a thickness of about 18 inches. In areas of higher water velocity, the erosion protection layer may be an articulated concrete revetment system in place of larger riprap. The revetment system would likely be about 10 inches thick. Placing additional sand and gravel will compensate for the difference in thickness between the armoring materials. To protect the lower banks, armoring will extend from the edge of the riverbed to a point on the banks above an appropriate flood level and anchored. The erosion protection layer will be installed on the bank after the bank slope has been graded to a stable slope (see Appendix N).

Several types of concrete revetment systems are available ranging from hand-placed individual interlocking blocks to large mattresses of blocks connected by cables and installed using conventional construction equipment. For this application, the cable-linked mattresses would be most appropriate and would provide the greatest protection against erosion. This system can be installed from the riverbanks or the riverbed. Above the normal water level, the void space within and between the blocks could be filled with soil and vegetated with shallow root species. Below the water level, the void spaces could be filled with sand and gravel. These types of systems provide a high degree of protection and would be most appropriate for use in areas with a high potential for erosion.

Assess the bioturbation potential of indigenous benthos and design a cap component to physically isolate soil or sediment contaminants from the benthic environment.

Bioturbation is the disturbance and mixing of sediments by benthic organisms. A riparian community characterization of the river completed for WESTON by Woodlot Alternatives, Inc. (Appendix K) suggests that there is little benthic activity in this portion of the river.

The erosion protection and sand and gravel layers of the proposed cap will serve as a physical barrier to potential bioturbation. Research indicates that bioturbation by benthic organisms in a sand layer is limited to the top 5 to 10 cm (2 to 4 inches) and that deeper burrowing organisms would be inhibited by the erosion protection layer (99-0224).

The erosion protection and sand and gravel layers are not expected to be immediately attractive to burrowing species until clean sediments are naturally deposited over these layers and in the interstices of the erosion protection material (99-0224). However, should any burrowing species inhabit the river in the future, the sorptive layer would be protected by 2 ft of erosion protection material, sand and gravel, a geotextile, and “new” sediment. Therefore it is unlikely that benthos would burrow into the sorptive layer.

Evaluate potential erosion at the capping site due to currents, waves, and propeller wash and design a cap component to stabilize the contaminated sediment or soil and other cap components.

The Housatonic River and its riverbanks are used primarily for recreational purposes such as walking, fishing, and canoeing. These activities may cause minor disturbance of the erosion protection layer but it is unlikely that integrity of the proposed cap would be significantly impacted.

The river is prone to sudden rises in water level following storm events, which significantly increase the volume and velocity of water. Along with the increase in water flow is a potential for debris to be washed into and along the river from surrounding areas. The erosion protection layer, in combination with the sand and gravel layer, should provide adequate protection from any erosive forces generated by higher than normal water flow. Similarly, these layers should provide enough physical separation between floating debris and the sorptive soil layer to prevent contact and potential damage. The erosion protection layer material will be selected (sized) consistent with water velocity, shear forces, and impact from floating debris and ice. Two feet of material above the sorptive soil layer will provide adequate protection from floating debris and human activities in the river (see Attachment M.1). In areas that historically have experienced significant erosion caused by increased water flow, ice or debris, a revetment system may be considered for use as the erosion protection layer.

Evaluate the potential flux of sediment or soil contaminants and design a cap component to reduce the flux of dissolved contaminants into the water column.

The Housatonic River is a gaining stream, which means that it is fed in part by groundwater. Therefore, there is a positive groundwater gradient through the sediment and lower bank soil that is typically below the river water level to the free water surface. In addition, with the rise and fall of river and groundwater levels during storm events, there will be associated inundation followed by draining of lower bank areas that are typically above the river water level. Consequently, advection of contaminants in these flow regimes is a transport mechanism that must be evaluated in the design of the sorptive soil layer. There will also be a PCB concentration gradient from the contaminated sediment and soil under the cap to the sorptive soil layer in the cap.

Diffusion is also a transport mechanism that must be considered in the “design” of the sorptive soil layer.

For the *Removal Action Work Plan – Upper ½-Mile Reach of the Housatonic River* (August 1999) (07-0020), GE and its contractor, Blasland, Bouck & Lee developed a model to evaluate the potential flux of PCBs through a “cap” from a PCB source to the water column. Using this model as a basis for sorptive layer design, sorptive layer thicknesses of 6 or 12 inches were proposed for the ½-Mile, depending on the underlying concentration of PCBs (i.e., 6 inches for PCBs <10; 12 inches for PCBs >10). For the purposes of this EE/CA cap analysis, this range of sorptive layer thicknesses has been assumed.

Evaluate potential interactions and compatibility among cap components, including consolidation of compressible materials.

The cap components and erosion protection layer (riprap, revetment systems, sand, gravel, silty sand, and geotextiles) are commonly used together in civil infrastructure and will be selected to ensure compatibility between adjacent cap components. For example, the geotextile will be selected such that it is capable of retaining the sorptive soil and separating the underlying sediment and overlying sand and gravel.

The compressibility of the sediments under the cap is not of particular concern as these deposits are relatively shallow. This is in contrast to sediment deposits in canals and lakes that can be more than 30 ft thick. The sediment is also predominantly sandy in composition and is therefore not expected to settle appreciably under the weight of the proposed cap. Any settlement of the sediments is expected to occur during construction so that, once installed, the cap will not be subjected to the potential effects of settlement.

Evaluate operational considerations and determine restrictions or additional protective measures (e.g., institutional controls) needed to ensure cap integrity.

As stated previously, the river is primarily used for recreational purposes such as walking, fishing, and canoeing. It is anticipated that the river will continue to be used for these purposes after the ISC has been installed. No additional activities are likely to develop in the river. As the river passes through an urban area, there is the potential that development activities (e.g., installation of replacement or new utility lines and roadways) will require that intrusive work be performed on the riverbanks or in the riverbed. In areas of the river where the cap is installed, a prohibition on intrusive activities is recommended. In this regard, local planning authorities should be made aware of the location of the cap and instructed to prohibit any intrusive activities that may in any way compromise the integrity of the cap. A mechanism (e.g., easements, activity and use limitations, etc.) should to be put in place whereby future development activities along the river are strictly controlled. Future construction permit applications for sites close to the river should be thoroughly reviewed by local authorities and by EPA to verify that the proposed construction will not interfere with the cap.

M.4 SELECTION OF MATERIALS

The following text develops the conceptual design of the cap components.

M.4.1 Sorptive Soil Layer

Physical Properties. The sorptive soil will be composed of a silty sandy soil with an organic (carbon) content of at least 0.5% placed between two geotextiles. Local borrow sources must be identified and soil samples tested to determine physical properties of the sorptive soil. As recommended by EPA, the tests presented in Table M-1 would be performed on the native borrow material and on any blended sorptive soil material.

Sorptive Properties. In addition to the physical properties listed above, "sorptive properties" must be specified. The sorptive soil will have an organic (carbon) content measured as total organic content [TOC] of at least 0.5%.

Geotextile. The sorptive soil will be encapsulated between two geotextiles. The mechanical and hydraulic properties (e.g., puncture and tear resistance and permittivity [cross-plane flow of water]) of the candidate geotextiles must be selected based on site-specific characteristics. In order to determine the required mechanical properties of the geotextiles, the maximum particle size and the angularity of any material that will contact the geotextiles must be estimated. The total load to be placed on the geotextiles must also be determined and will be a function of the thickness of each subsequent layer of material and the unit weight of the materials that comprise those layers and the forces imposed on the material during cap installation.

Table M-1

Suggested Physical Properties for Sorptive Soil Layer*

Property	Test Method	Range of Acceptable Values
Natural Moisture Content	ASTM D 2216	10 to 18%
Grain Size Distribution	ASTM D 421/422	15% gravel with D_{max} $\leq$1 in. 65% sand 20% fines
Atterberg Limits	ASTM D4318	LL = 30 to 40 PI = 4 to 12
Soil Classification	ASTM D 2487	SM, SM-SC
Moisture, Ash, Organic Content	ASTM D 2974	2 to 5%
Specific Gravity	ASTM D 854	For information only
Consolidation	ASTM D 2435 (as modified by USACE 1987)	For information only
Permeability	ASTM D 2434	For information only

*Subject to change based on availability.

Geotextiles can be broadly divided into two families, woven and nonwoven. Typically, woven geotextiles are used as reinforcement and separation materials. Nonwoven geotextiles are primarily used as filter and cushioning materials. The primary function of the geotextiles to be used as part of the sorptive soil layer will be to act as filters. The geotextiles will limit the migration of sediment and the sorptive soil upward through the water column. If necessary, woven geotextiles may have to be substituted or used in conjunction with nonwoven geotextiles in order to satisfy strength requirements.

Procedures presented by Koerner (99-0222) and others allow the mechanical properties of geotextiles to be selected based on function and site-specific conditions. For this project, geotextiles with a mass per unit area of 12 to 16 oz/yd^2 and the following mechanical properties would likely be suitable for use.

Table M-2

Suggested Mechanical Properties for Geotextile

Mechanical Property	Required Value*	ASTM Test Method
Puncture	180 lb (800 N)	D 4833
Burst	600 psi (4130 kPa)	D 3786
Trapezoidal Tear	115 lb (510 N)	D 4533
Grab Tensile	300 lb (1335 N)	D 4632

Note: *Suggested required values. Actual values to be determined during final design stage using appropriate procedures.

Filtration criteria for the geotextiles can be determined using a procedure outlined in the Federal Highway Administration (FHWA) *Geosynthetic Design & Construction Guidelines* (Holtz, et al., 99-0221). The required hydraulic properties of the geotextile, namely permittivity (cross-plane flow) and apparent open size (AOS), are a function of the particle size and permeability of the soils in contact with the geotextiles. The geotextiles must allow water to flow freely, without clogging, while preventing the movement of sediment particles (filtration requirement) into the sorptive soil layer and preventing the loss of soil from the sorptive layer into the overlying sand and gravel layer. The geotextiles will be designed to satisfy the retention, permeability/ permittivity, and clogging resistance criterion presented in the FHWA manual.

In order to specify requirements for the geotextiles, it is necessary to obtain grain size data for river sediment, sorptive soil, and the sand and gravel bedding material. Grain size analysis test results for river sediment are available; however, grain size data for the sorptive soil are not available as a source has not yet been identified. Suggested grain size distribution for the sand and gravel layer is presented in the following subsection. Following are suggested hydraulic properties for the geotextiles. Note that it may be necessary to use two geotextiles, each with different hydraulic properties.

Table M-3

Suggested Hydraulic Properties for Geotextiles

Hydraulic Property	Required Value*	ASTM Test Method
Permittivity	$\geq 0.5\ sec^{-1}$	D 4491
AOS	≤ 0.2 mm	D 4751

Note: * Suggested required values. Actual values to be determined during final design stage using appropriate procedures.

There are numerous commercially available geotextiles that will meet these requirements. Specific products and manufacturers are not identified so as to avoid endorsement of any product or manufacturer.

M.4.2 Sand and Gravel Layer

The sand and gravel layer will function as a bedding layer for the overlying erosion protection layer. This layer will be composed of select gravel, sand, and low- to non-plastic fines to protect the underlying geotextile of the cap from damage. The geotextile placed directly beneath the sand and gravel layer will serve two functions, filtration and separation. Since the geotextiles will meet filtration requirements, the bedding layer material does not have to serve this function. A sand and gravel bedding layer material having a maximum particle size of 3 inches with about 15% gravel, 65% sand, and about 20% fines, i.e., material passing the #200 sieve, will provide a bedding layer that will protect the underlying geotextile(s) and remain stable.

The gradation requirements are summarized in the following table.

Table M-4

Suggested Sand and Gravel Layer Gradation*

Sieve Size	Percent Passing by Weight
3”	100%
2”	95 – 100%
1”	85 – 95%
No. 4	75 – 90%
No. 20	30 – 70%
No. 40	20 – 50%
No. 100	15 – 30%
No. 200	10 - 25%

* Subject to change based on availability.

In addition to gradation requirements, organic content, liquid limit, and plasticity index values will also be specified. Material would also have to meet the quality and durability requirements of the Massachusetts Highway Department Standard Specifications. The selection of this material may be modified in order to realize economic benefit and to take advantage of locally available material.

M.4.3 Erosion Protection Layer

The erosion protection layer prevents erosion of soil materials placed over the riverbed and lower riverbanks following the removal action. The same protection may be used for areas that may be capped or that may be excavated to the cleanup criteria set for the EE/CA. However, in uncapped areas excavated to the cleanup criteria, restoration to match existing substrates (sand and/or gravel) will be possible, and will likely be considered advantageous with regard to reestablishing and enhancing aquatic habitat.

The evaluation of the armor protection will follow EPA guidance (99-0224) and the USACE Engineering and Design Manual *Hydraulic Design of Flood Control Channels* (USACE EM 1110-2-1601) (99-0227). The potential for erosion depends on stream flow velocity forces, depth, turbulence, boat traffic, physical characteristics of the sediment, and ice and debris impact (EPA). Of these considerations, boat traffic can be ignored as the river is shallow in the Upper Reach and powerboats are not typically used.

River Flows at Pittsfield. The East Branch of the Housatonic River drains an area of approximately 70.8 square miles located predominantly north and east of Pittsfield. The Housatonic River is characterized as a “flashy” river in that it responds quickly to precipitation, rising rapidly after the start of a rainstorm and quickly returning to base flow after the cessation of precipitation.

The estimated average daily discharge flow in the Housatonic River at Pittsfield is 124 cubic feet per second (cfs), with a minimum average daily flow of 5.1 cfs and a maximum average daily flow of 5,174 cfs. The 80% average daily flow (the average daily flow that is reached or exceeded 80% of the time) is 36 cfs. Similarly, the 50% and 20% average daily flows are 70 cfs and 165 cfs, respectively. The estimated annual peak discharge for the Housatonic River at Pittsfield has ranged from 457 cfs in 1965 to 7,424 cfs in 1938.

The estimated Housatonic River peak flows in Pittsfield at the storm events are summarized in Table M-5:

Table M-5

Housatonic River Peak Flows in Pittsfield

Storm Event	Discharge (cfs)
2-year	1,880
10-year	4,286
25-year	6,154
50-year	7,913
100-year	10,044

Return Interval. The return interval or frequency of events associated with storms/floods used in the design of erosion protection depends on several factors including the degree of risk associated with re-exposure to the contaminants. The design life of civil projects such as storm channels, bridges, and dams typically ranges from 25 to 50 years. The return interval used in the design of such structures is therefore up to 100 years.

Work by BBL presented in *the Removal Action Work Plan – Upper ½ Mile Reach of the Housatonic River* (August 1999) (07-0020) concluded that flows approaching 6,000 cfs produced the maximum flow velocities. At flows above this level, velocity became limited as the effect of the floodplains (out of bank flow) reduced the average velocities in the river. WESTON review of the data confirmed this conclusion. The 6,000-cfs flow was estimated by BBL to correspond to the 25- to 30-year return interval and was the flow used for the armor design in the Removal Action Work Plan (07-0020).

For the erosion protection material evaluation of the 1 ½-mile portion of the Upper Reach, the 6,000-cfs flow was used with Manning's Equation to determine the flow depth and velocity at specific river cross sections under future (restored) conditions. In instances where the 6,000-cfs flow overtopped the riverbanks, Manning's Equation was solved for top of bank flow depth.

Selection of River Cross Sections. A total of 11 cross sections were selected as representative of the EE/CA Reach. The cross sections correspond to the river transects and subreaches listed in Table M-6.

Table M-6

River Transects and Subreaches

Transect	Subreach
70	3-8
90	3-9
104	3-10
110	4-1
122	4-2
134	4-3
160	4-4B
170	4-5A
180	4-5A
198	4-6
206	4-6

Determination of Flow Characteristics. Manning's Equation was used to determine the flow depth and velocity at specific river cross sections under future (restored) conditions. Manning's Equation requires a river cross section (see above), the determination of an "n" value representing the roughness of the river cross section, a channel bed slope, and a flow rate.

The value of "n" was determined using equation 5-12 and Table 5-5 from Chow (99-0219). The equation is:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4) \times m_5 \qquad (5\text{-}12)$$

Where:

n_0 = base n value for the channel material
n_1 = degree of irregularity
n_2 = variations in channel cross section
n_3 = relative effect of obstructions
n_4 = vegetation
m_5 = degree of meandering

The average channel bedslope over the length of the EE/CA Reach is 0.00167 ft/ft. The maximum slope occurs near transect 116 with a slope of 0.05333 ft/ft. For the purpose of this evaluation a slope of 0.01 is used for solving Manning's Equation.

As stated above, the Erosion Protection Material evaluation of the EE/CA Reach is based on the 6,000-cfs flow except in instances in which the 6,000-cfs flow overtopped the riverbanks. In such instances, top-of-bank flow depths were used.

Determination of Stone Size. The calculation of the size of stone erosion protection material follows EPA guidance (99-0224) and the USACE Engineering and Design Manual EM 1110-2-1601 (99-0227). See Attachment M.1 for calculations of stone size for straight river sections.

The median stone (D50) size based upon preliminary hydraulics analysis for the majority of the river is 0.50 ft, except at transect 160, where a D50 of 0.75 ft was calculated. Should vandalism and/or theft of stones be considered a serious threat to the stability of the erosion protection or to public health and safety, larger stone (D50 = 12 inches, W50 = 80 lb) may be specified. The gradation of these stone sizes from Table 3-1 (99-0224) are presented below:

Table M-7

Limits of Stone Weight (lb) for Percentage Lighter by Weight

	D100 (maximum)	**D50 (median)**	**D15**
D50 = 0.50 ft			
Size (in.)	12	6	
Weight (lb)	86 - 35	26 - 17	13 - 5
D50 = 0.75 ft			
Size (in.)	15	9	
Weight (lb)	169 - 67	50 - 34	25 - 11
D50 = 1.0 ft			
Size (in.)	18	12	
Weight (lb)	292 - 117	86 - 35	43 - 18

Stone will be placed to a thickness of 1 times D100 plus allowances for ice and debris flow. From EM 1110-2-1601 (99-0227), this allowance is between 6 and 12 inches. An increase in stone size is also warranted in areas of heavy debris flow. In areas where stone having a D50 of 0.50 ft is used, the stone will be placed to a minimum thickness of 18 inches. In areas where stone having a D50 of 0.75 ft is used, stone will be placed to a minimum thickness of 21 inches. The use of articulated concrete revetment systems are recommended in this area to minimize the depth of excavation required to install the cap and erosion protection layer. For the purpose of this EE/CA, a stone armor having a D50 of 0.5 ft placed 18 inches thick is assumed throughout the EE/CA Reach. The actual stone size and thickness may vary during the predesign phase of the project.

In areas where larger erosion protection is required (at river bends, bridges, channel transitions, and other restrictions to flow), the larger erosion protection will extend a sufficient distance upstream and downstream of the area requiring the heavier armor. This distance can range from 1.5 to 5.0 “river widths” depending upon site conditions and flow through that portion of the river.

Limits of Stone Placement. Stone erosion protection will be placed in selected locations of the riverbed and along the toe of bank and lower banks in the EE/CA Reach. The stone will be placed to a height 6 ft (vertical) above the normal river flow level (corresponding to a flow of 124 cfs). This elevation is above the elevation of the 2-year storm flow (1,880 cfs). Above this elevation native vegetation, erosion control blankets, or suitable bioengineered techniques will be used to stabilize the banks. It is noted that based on final design considerations and the results of detailed design of enhanced habitat restoration in the riverbed, much of the riverbed area will not have armor stone if no sorptive cap is present.

M.5 CONSTRUCTION METHODOLOGY

Construction and installation of a cap in the riverbed and the lower banks would be likely more difficult with the river flowing, as would be the case with wet excavation. Soil could be washed downstream, necessitating the installation and maintenance of erosion and sedimentation control devices. Although more feasible in standing water, the procedure would still be more practical in a dry condition. Installing the sorptive cap in a dry condition would reduce the potential for erosion and permit better quality control inspection of the cap subgrade and cap installation.

An alternate approach to placing the sorptive soil in the “wet” may be to prefabricate sorptive soil “bags” in a staging area, and then lower each “bag” into position in the riverbed. The bags would be constructed of geotextiles sewn into a mattress filled with the sorptive soil. This may be appropriate for straight sections of the river but would require custom fabrication of curved section for bends and to accommodate obstructions in the river. However, the weight of prefabricated “bags” would likely require large construction equipment that may not be usable in many areas of the site due to restricted access and relatively long reaches from the top of bank to the riverbed.

Following is a description of steps involved in constructing a cap. It is assumed that the work would be completed in a dry condition by diverting flow around the active excavation/cap installation area using a nonintrusive river diversion method. This description does not address cap installation using intrusive river diversion (sheetpiling) when the area to be capped extends beyond the area to be diverted. This description also does not address the removal of sediment from the riverbed or the riverbanks.

M.5.1 General

It is anticipated that the cap would be installed in a two-phase operation following sediment and bank soil removal. Prior to placing sorptive soil, a geotextile will be deployed on the excavated surface. Following placement of the sorptive soil layer, the upper geotextile will then be deployed followed by the sand and gravel and erosion protection layers. Upon completion of phase one, phase two construction would begin by diverting flow on top of the newly constructed cap. The removal and installation procedures described above would be repeated for phase two construction. The tie-in between phase one and phase two construction would be completed as part of phase two construction and would use geotextile flaps installed during phase one. This tie-in procedure is described in this text and is illustrated in Figure M-2. If the entire flow of the river is bypassed around the area to be capped, the two-phase construction would not be required.

M.5.2 Installation of Sorptive Soil Layer

Following removal of sediment from the riverbed and banks to the required depth, the lower geotextile would be placed atop sediment or bank soil to remain in place. During phase one, geotextile would be extended from approximately the centerline of the river to a point along one bank approximately 6 vertical ft above the normal river flow level (this assumes capping of the entire river channel). Prior to placing the sorptive soil, a geotextile flap will be added along the panel edge parallel to the centerline of the river. This flap will overlap the installed panel by at least 3 ft and will be long enough to overlap the next adjacent panel (installed during phase two) by at least 3 ft (see Figure M-2). The flap must be protected during placement of the sorptive soil, sand, and gravel and erosion protection layers.

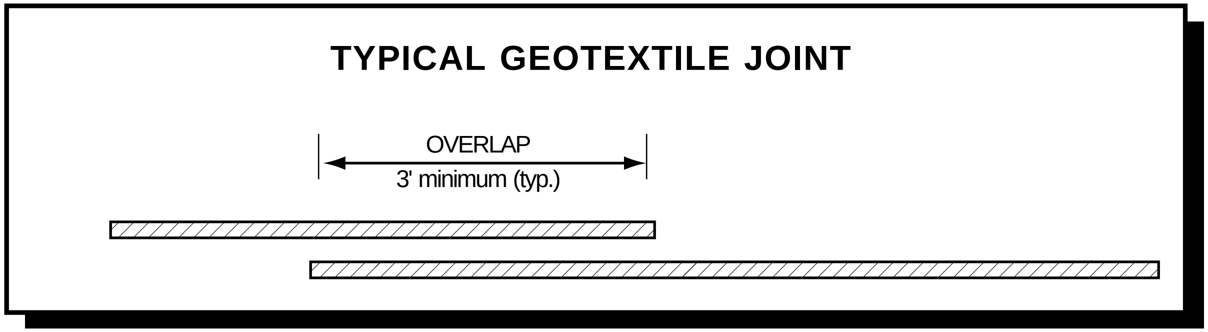
The sorptive soil would then be placed to the required thickness using conventional construction equipment. Following placement of the sorptive soil, the upper geotextile would be set in place and the longitudinal joints formed, i.e., the seams along the centerline of the river and on the bank. Adjacent downstream geotextile panels would be sewn together or overlapped by at least 3 ft.

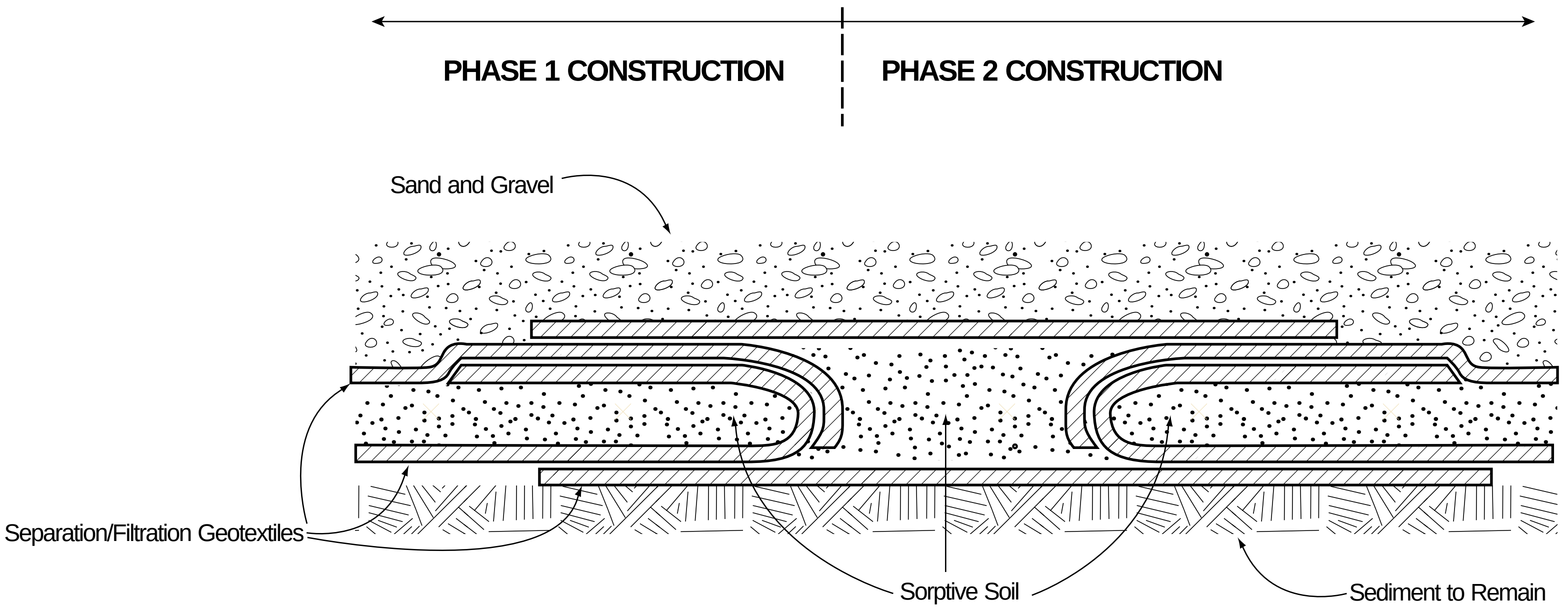
If only a riverbank cap is to be installed, the work would be completed in a single phase. The geotextile and the sorptive soil layer would only be installed along the riverbank and would terminate in an anchor trench at the interface of the riverbank and riverbed. Figure M-5 shows a typical transition that would be applicable in this situation.

M.5.3 Installation of Sand and Gravel Layer

The sand and gravel layer will be placed atop the upper geotextile of the sorptive soil layer. The layer will extend above the sorptive soil layer termination points on the riverbanks. The sand and gravel will be placed to a thickness of about 6 inches.

Conventional construction methods could be used to place the material. Extreme care must be exercised to ensure the upper geotextile of the sorptive soil layer is not damaged during placement and leveling of this layer. Where the entire channel is being capped, care must also be exercised to ensure that this material does not slough into the area along the centerline of the river where the sorptive layer is temporarily terminated between phase one and phase two construction. The sand and gravel could be placed in dry or wet conditions but again, to provide for inspection and reduce the potential of damaging the sorptive soil layer, a dry condition is preferred.





LEGEND

Sand and Gravel
Sorptive Soil
Sediment
Geotextile

ENGINEERING EVALUATION/COST ANALYSIS
Upper Reach of the Housatonic River
Pittsfield, Massachusetts

FIGURE M-2
CONNECTION BETWEEN PHASE 1 AND PHASE 2 CAP CONSTRUCTION

99P-1934c

M.5.4 Installation of Erosion Protection Layer

The erosion protection material will be extended across the riverbed and up the bank to a point about 6 vertical ft above the normal river flow level to protect the riverbed and lower riverbanks from erosion, debris impact, and ice. If riprap is used, it will be terminated on the slope with an immediate transition to soil cover or retaining structure on the upper slope.

If a revetment system is used for erosion protection, it must be anchored at its termination point prior to transitioning to soil cover on the upper slope (see Figure M-3). The anchor length required will be dependent on slope length and inclination and shear forces due to water velocity. Construction equipment will be required to place the armoring materials.

Placement of the erosion protection layer in dry or wet conditions is feasible. However, it is likely that placing the materials in a wet condition would cause turbid conditions. To restore more natural-like conditions, the void spaces in the erosion protection layer on the slope below the water level could be filled with sand and gravel while above the water level the void spaces could be filled with soil and the surface vegetated.

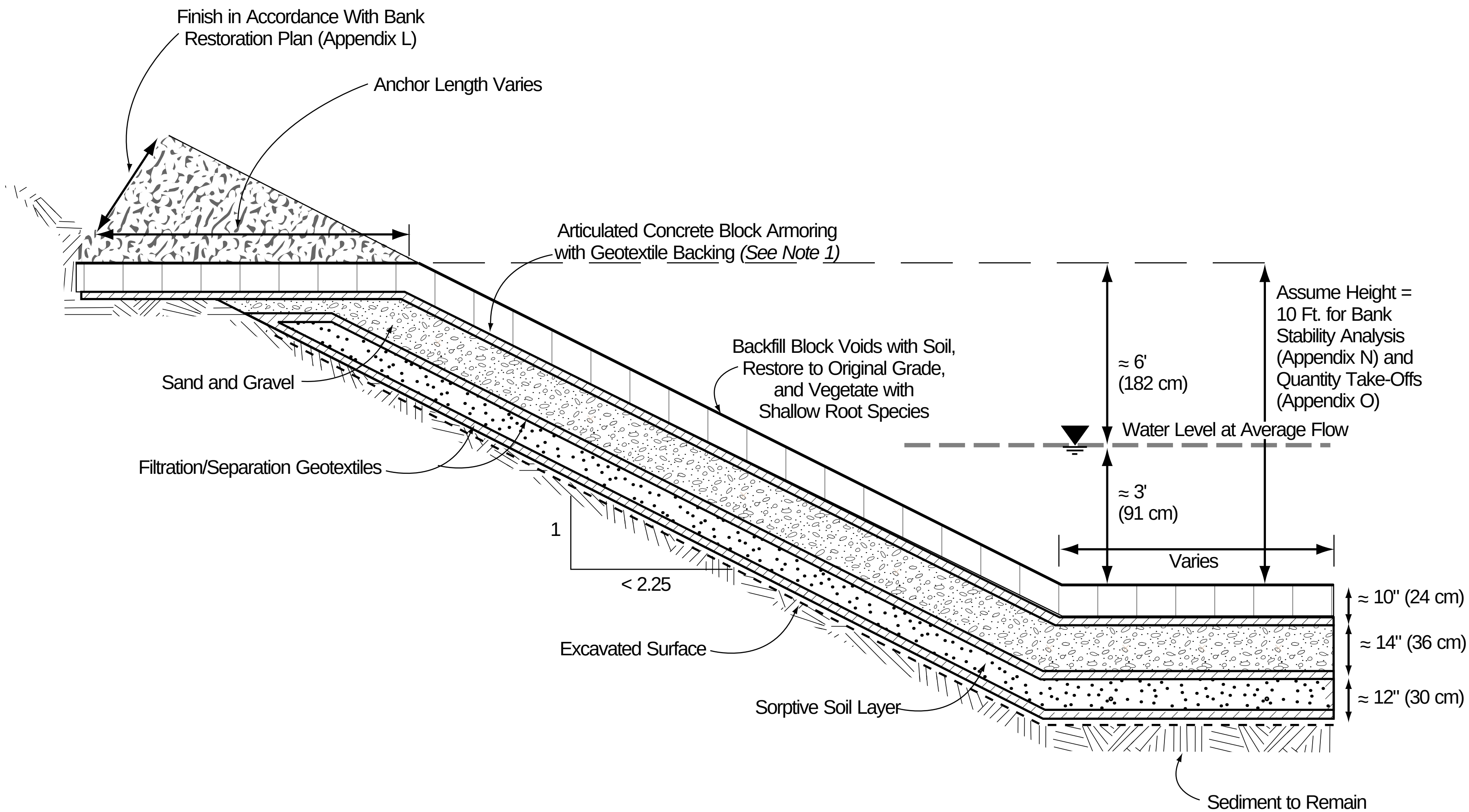
M.5.5 Completing the Cap Installation

Note: This subsection only applies to cases where the entire river channel is being capped and a nonintrusive barrier is used for river diversion.

In order to complete the tie-in between phase one and phase two construction, it is assumed that water flow can be diverted into about one-third of the existing channel width. Doing so will allow construction of the cap up to about the centerline of the river during both phases. A zone of approximately 5 ft along the centerline of the river will not be completed during phase one. This will be part of the tie-in work to be completed during phase two construction. It is assumed that flow can be diverted over the completed phase one work area while preventing flow from entering the tie-in area. With flow diverted onto the phase one work area, cap construction and tie-in work of phase two can be completed. The construction sequence is illustrated in Figure M-4.

M.5.6 Transition Between Capped and Non-Capped Areas

The transition from capped to non-capped areas (and vice versa) will be made by constructing an anchor trench for the sorptive soil layer at the termination of the cap (see Figure M-5). The anchor trench will reduce the potential for contamination to bypass the sorptive soil layer into the water column. The overlying sand and gravel layer and erosion protection layer would be continuous across the transition.



LEGEND

Articulated Concrete Block

Sand and Gravel

Sorptive Soil

Sediment

Geotextile

Water Level

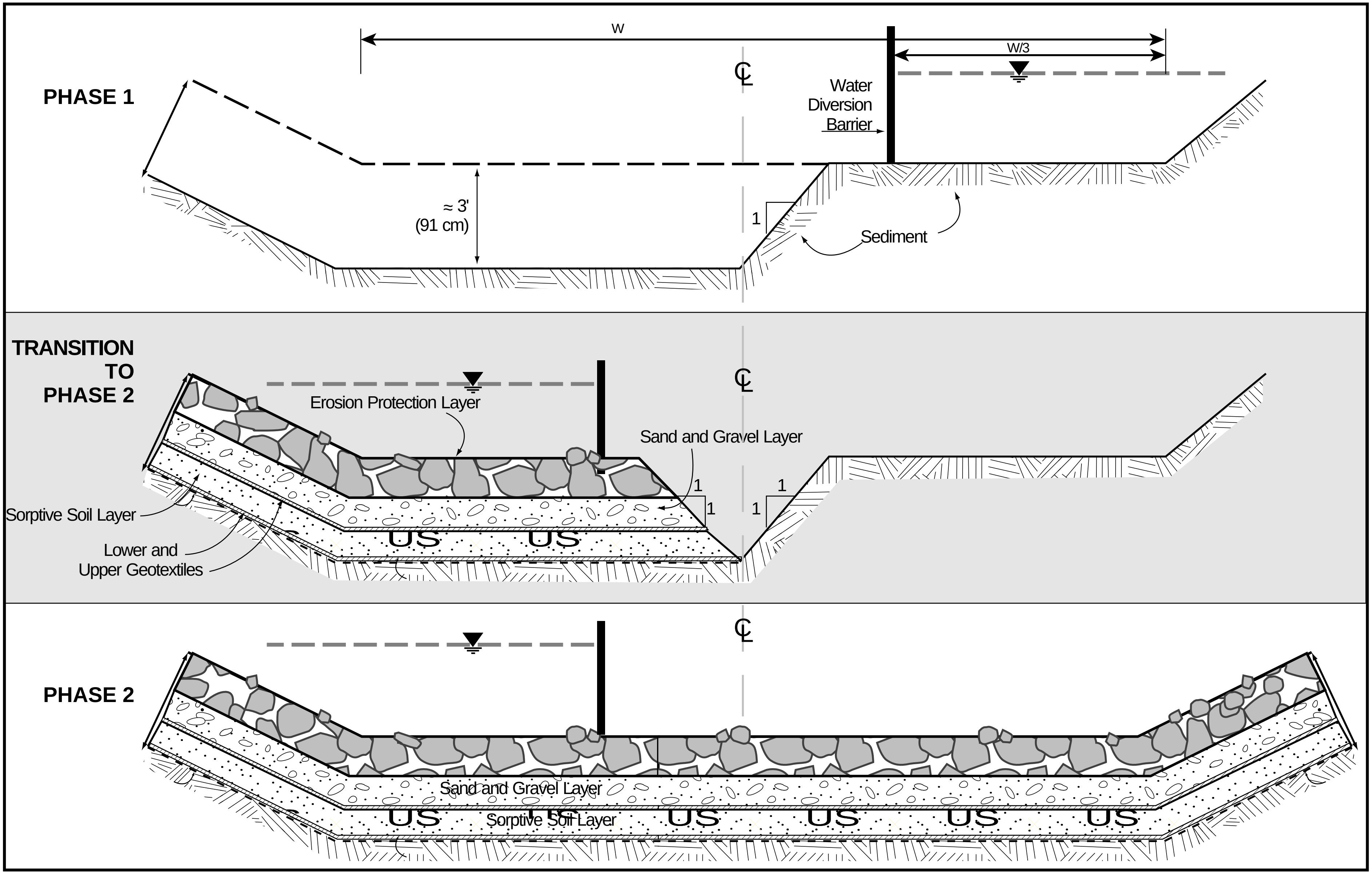
Select Fill

Note 1: Erosion protection material will vary depending on water velocity, shear forces, and slope inclination.

ENGINEERING EVALUATION/COST ANALYSIS
Upper Reach of the Housatonic River
Pittsfield, Massachusetts

FIGURE M-3
TYPICAL SECTION AT TRANSITION FROM RIVERBED TO RIVER BANK IN AREAS WITH HIGH EROSION POTENTIAL

99P-2827 12/8/99



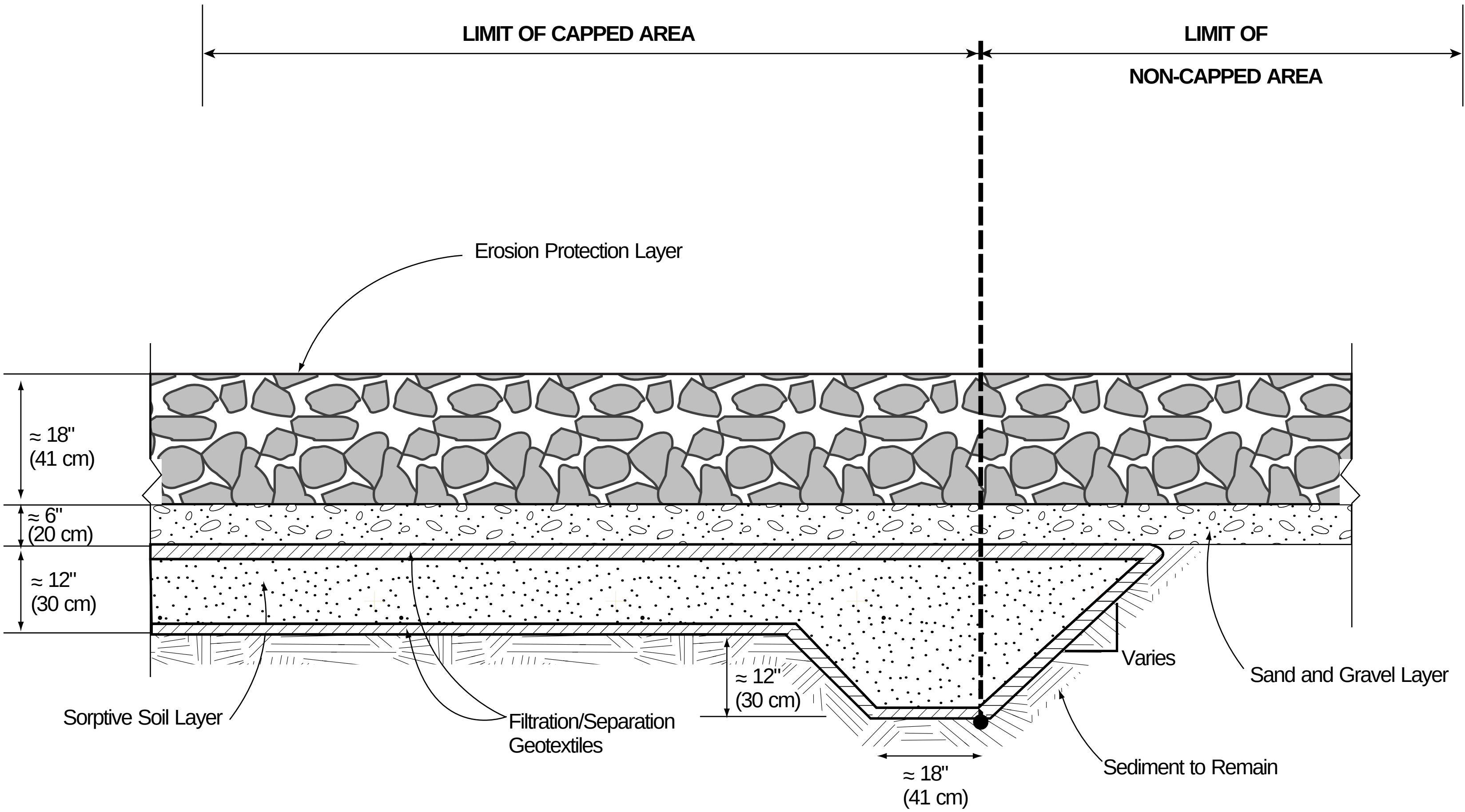
LEGEND

- Erosion Protection Material
- Sand and Gravel
- Sorptive Soil
- Sediment
- Geotextile
- Water Level

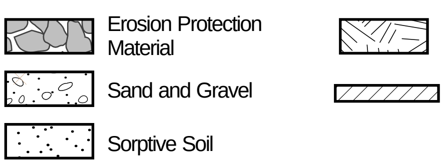
ENGINEERING EVALUATION/COST ANALYSIS
Upper Reach of the Housatonic River
Pittsfield, Massachusetts

FIGURE M-4
CONSTRUCTION SEQUENCING

99P-2944d



LEGEND



Erosion Protection Material	Sediment
Sand and Gravel	Geotextile
Sorptive Soil	

ENGINEERING EVALUATION/COST ANALYSIS
Upper Reach of the Housatonic River
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FIGURE M-5
TYPICAL SECTION AT TRANSITION FROM CAPPED TO NON-CAPPED AREAS

99P-2944j

M.6 ADDITION OF HABITAT ENHANCEMENT FEATURES

The above discussions addressed the basic components of a cap. As described, a cap would be installed on a uniform surface and would be 3 ft thick when complete. In order to accommodate habitat enhancement features such as pools and riffles, localized areas of overexcavation will be required. The location of pools and riffles would be selected to maximize their beneficial impact on habitat. Large boulders and riprap could also be placed above the water level in order to provide shade for fish. The use of other habitat enhancement features could also be incorporated into the cap design and construction but will require more detailed analysis and is beyond the scope of this discussion.

ATTACHMENT M.1

CALCULATION OF EROSION PROTECTION MATERIAL SIZE

ATTACHMENT M.1

CALCULATION OF EROSION PROTECTION MATERIAL SIZE

OBJECTIVE

Estimate the protection required to prevent erosion of soil materials placed over the riverbed and lower riverbanks during the restoration of the Upper Reach of the Housatonic River following removal action. For this EE/CA the erosion protection material will be stone riprap, and the same protection will be used for areas that may be capped or that may be excavated to the cleanup criteria set for the EE/CA. Other erosion protection materials may be selected during final design of the restoration including sand or gravel in less erosive portions of the river and riverbank environment.

INTRODUCTION

The evaluation of the stone protection will follow the EPA ARCS Program *Guidance for the In Situ Subaqueous Capping of Contaminated Sediments* (99-0224) and the USACE Engineering and Design Manual *Hydraulic Design of Flood Control Channels* (USACE EM 1110-2-1601) (99-0227).

Limitation of This Calculation

The stone size determined here is preliminary and is intended for use in the EE/CA only. A detailed design program should be undertaken to determine the final armor size. This detailed design must take into account:

- Detailed hydrologic and hydraulic calculations.
- Surveyed river cross sections and projected restored river cross sections.
- The final restored river composition.
- Effects of river bends, bridges, channel transitions, and other restrictions to flow.
- Effects of local storm sewer outfalls into the river.

EE/CA for the Upper Reach of the Housatonic River
Pittsfield, MA

Hydrology & Hydraulics Calculations

Computation of Manning's "n"

From Table 5-5 of Chow (1959) compute the Mannings "n" value for the river bottom, river banks, and floodplain.
Use eqn. 5-12 (Chow 1959) for the computation…

n=(n0+n1+n2+n3+n4)m5

n0 = basic n value for material involved
n1 = degree of irregularity in the channel
n2 = degree of variation in the channel cross section
n3 = relative effect of obstructions
n4 = vegetation
m4 = degree of meandering

EXISTING CONDITIONS:

River Bottom

n0 =		0.024	fine gravel
n1 =		0.005	minor
n2 =		0.005	alternating occasionally
n3 =		0.010	minor
n4 =		0.000	no vegetation in river
m4 =		1.000	minor
	n=	0.044	(use n=0.045)

River Banks

n0 =		0.024	fine gravel
n1 =		0.010	moderate
n2 =		0.010	alternating frequently
n3 =		0.025	appreciable
n4 =		0.030	high
m4 =		1.000	minor
	n=	0.099	(use n=0.100)

Floodplain

n0 =		0.024	fine gravel
n1 =		0.020	severe
n2 =		0.010	alternating frequently
n3 =		0.025	appreciable
n4 =		0.070	very high
m4 =		1.000	minor
	n=	0.149	(use n=0.150)

EE/CA for the Upper Reach of the Housatonic River
Pittsfield, MA

Hydrology & Hydraulics Calculations

FUTURE CONDITIONS:

River Bottom

n0 =		0.028	coarse gravel
n1 =		0.005	minor
n2 =		0.000	gradual
n3 =		0.010	minor
n4 =		0.005	low
m4 =		1.000	minor
	n=	0.048	(use n=0.050)

River Banks

n0 =		0.028	coarse gravel
n1 =		0.005	minor
n2 =		0.005	alternating occasionally frequently
n3 =		0.025	appreciable
n4 =		0.010	medium
m4 =		1.000	minor
	n=	0.073	(use n=0.075)

Floodplain

n0 =		0.024	fine gravel
n1 =		0.020	severe
n2 =		0.010	alternating frequently+E43
n3 =		0.025	appreciable
n4 =		0.070	very high
m4 =		1.000	minor
	n=	0.149	(use n=0.150)

EE/CA for the Upper Reach of the Housatonic River
Pittsfield, MA

Hydrology & Hydraulics Calculations

Selected Cross Sections

The following transects (channel cross sections) have been selected as representative of the upper reach.

Transect	Subreach
70	3-8
90	3-9
104	3-10
110	4-1
122	4-2
134	4-3
160	4-4B
170	4-5A
180	4-5A
198	4-6
206	4-6

Computation of Uniform Flow Characteristics by Transect

Manning's eqn. will be used to dermine uniform flow characteristics of each transect. The maximum flow capacity and velocities typically occur at bankfull conditions before flow reaches the floodplain. The calculation of flow capacity and maximum velocities at bankfull will be used for analysis of armor requirements.

Bedslope:

The average channel bedslope thoughout the run of the EE/CA is 0.00167 ft/ft. The maximum bedslope occurs in the vicinity of transect 116 (0.05333 ft/ft). For the purpose of this evaluation use an average bedslope value of 0.01000 ft/ft.

Computation:

EXISTING CONDITIONS

Manning's equation for each transect is solved using FlowMaster by Haestad Methods, Inc. The program calculates a weighted Manning's n based on flow depth, determines the capacity of the channel at bankfull, and the corresponding flow velocity. A rating table for flow depths 2 ft below to 2 ft above bankfull will be produced showing Q and V for comparison to the bank+C7full elevation.

Bank-full flow under existing conditions (Summary):

Transect	Weighted n Value	Bank-full Depth (ft)	Flow (cfs)	Velocity (fps)
70	0.062	10	7,415	9.1
90	0.063	14	8,816	9.3
104	0.071	23	19,052	11.6
110	0.081	22	12,582	9.7
122	0.084	16	7,353	7.9
134	0.070	14	6,927	8.5
160	0.067	9	3,279	7.0
170	0.067	12	6,473	8.1
180	0.067	10	3,486	7.2
198	0.054	12	6,330	10.4
206	0.049	10	4,898	9.9

EE/CA for the Upper Reach of the Housatonic River
Pittsfield, MA

Hydrology & Hydraulics Calculations

FUTURE CONDITIONS

Manning's equation for each transect is solved using FlowMaster by Haestad Methods, Inc. The program calculates a weighted Manning's n based on flow depth, determines the capacity of the channel at bankfull, and the corresponding flow velocity. A rating table for flow depths 2 ft below to 2 ft above bankfull will be produced showing Q and V for comparison to the bankfull elevation.

Bank-full flow under future conditions (Summary):

Transect	Weighted n Value	Bankfull Depth (ft)	Flow (cfs)	Velocity (fps)
70	0.061	10	7,894	9.5
90	0.063	14	9,712	9.6
104	0.066	23	20,550	12.5
110	0.066	22	16,201	12.1
122	0.067	16	8,986	9.8
134	0.051	14	10,854	12.5
160	0.050	9	5,760	10.2
170	0.070	12	6,509	8.0
180	0.053	10	5,128	9.4
198	0.061	12	6,540	9.6
206	0.058	10	4,814	8.6

COMPARE EXISTING TO FUTURE CAPACITY

Transect	Existing Flow (cfs)	Future Flow (cfs)	Increase in Flow Capacity (cfs)
70	7,415	7,894	479
90	8,816	9,712	896
104	19,052	20,550	1,498
110	12,582	16,201	3,619
122	7,353	8,986	1,633
134	6,927	10,854	3,927
160	3,279	5,760	2,481
170	6,473	6,509	36
180	3,486	5,128	1,642
198	6,330	6,540	210
206	4,898	4,814	-84
		Average =	1,485

River capacity increases an average of 1,485 cfs at each section studied under bankfull conditions.

EE/CA for the Upper Reach of the Housatonic River
Pittsfield, MA

Hydrology & Hydraulics Calculations

Size the Riprap for the Riverbed and Banks

Use USACE Engineering and Design Manual Hydraulic Design of Flood Control Channels (EM 1110-2-1601, 1994) and USEPA ARCS Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (EPA 905-B96-004) to size the riprap.

from the computation of uniform flow through the selected transects…

Bank-full flow under future conditions (Summary):

Transect	Bankfull Depth (ft)	Flow (cfs)	Velocity (fps)
70	10	7,894	9.5
90	14	9,712	9.6
104	23	20,550	12.5
110	22	16,201	12.1
122	16	8,986	9.8
134	14	10,854	12.5
160	9	5,760	10.2
170	12	6,509	8.0
180	10	5,128	9.4
198	12	6,540	9.6
206	10	4,814	8.6

For the 0.5-mile removal reach, BB&L (for GE) conducted HEC-2 analyses to develop their channel protection design. The BB&L analyses indicate that the maximum velocity occurs at discharges of 6,000 cfs. This is reasonable and corresponds to a nearly bankfull condition on the Upper Reach in Pittsfield, MA. The 6,000-cfs flow corresponds closely with a 30-year storm event (recurrance interval).

For the engineering evaluation of the EE/CA Reach the basis of design of riprap protection will be a flow of 6,000 cfs or, if 6,000 cfs overtops the banks, bank-full condition calculated previously.

FUTURE CONDITIONS WITH FLOW SET AT 6,000 CFS

Manning's equation for each transect is solved using FlowMaster by Haestad Methods, Inc. The program calculates a weighted Manning's n based on flow depth and the corresponding flow depth and velocity. The flow rate is set at 6,000 cfs to determine water surface elevation.

Transect	Weighted n Value	Bankfull Depth (ft)	Flow Depth (ft)	Velocity (fps)	Controlling Condition
70	0.060	10	8.5	8.8	6,000 cfs
90	0.063	14	11.2	8.6	6,000 cfs
104	0.066	23	12.6	9.5	6,000 cfs
110	0.066	22	13.3	9.6	6,000 cfs
122	0.067	16	13.2	8.9	6,000 cfs
134	0.051	14	11.4	9.3	6,000 cfs
160	0.050	9	10.3	7.5	Bank-full
170	0.070	12	10.7	8.8	6,000 cfs
180	0.053	10	11.6	7.7	Bank-full
198	0.061	12	11.5	9.4	6,000 cfs
206	0.058	10	11.3	7.6	Bank-full

EE/CA for the Upper Reach of the Housatonic River
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Hydrology & Hydraulics Calculations

Riprap Calculation

EPA 905-B96-004 recommends the following equation (modified from EM 1110-2-1601) to determine the median stone diameter (D50) for a riprap layer:

D50 = Sf x Cs x Cv x Ct x Cg x d x ((Dw/(Ds-Dw))^0.5) x (V/(K1 x g x d)^0.5))^2.5

Sf =	Safety Factor	1.1	(minimum = 1.1)
Cs =	Stability Coef.	0.3	angular rock
Cv =	Velocity Distrib	1	typ. for straight channels
Ct =	Thickness Coef.	0.85	(Plate B-40)
Cg =	Gradation Coef	1.2	(D85/D15)^.333
d =	Local Depth	varies	(Channel Depth)
Dw =	Density of Water	62.4	
Ds =	Density of Stone	165	(minimum)
V =	Velocity	varies	
K1 =	Slope Correction	0.7751	(see below)
g =	Gravity constant	32.2	

(Dw/(Ds-Dw))^0.5 = 0.7799

K1 = ((1-(sin^2a)/(sin^2b))^0.5

a =	Side slope angle	(2.25H:1V)	23.962 degrees
b =	Riprap angle of repose		40.000 degrees

K1 = 0.7751

Transect	Depth (ft)	Velocity (fps)	D50 (ft)	Use D50 of (ft)
70	8.5	8.8	0.44	0.50
90	11.2	8.6	0.38	0.50
104	12.6	9.5	0.48	0.50
110	13.3	9.6	0.48	0.50
122	13.2	8.9	0.40	0.50
134	11.4	9.3	0.47	0.50
160	9.0	10.2	0.62	0.75
170	10.7	8.8	0.41	0.50
180	10.0	9.4	0.49	0.50
198	11.5	9.4	0.48	0.50
206	10.0	8.6	0.40	0.50

EE/CA for the Upper Reach of the Housatonic River
Pittsfield, MA

Hydrology & Hydraulics Calculations

Height of Erosion Protection on Banks

Normal (average) flow in the Housatonic River is 124 cfs.
The 2-year flow is 1,880 cfs.
Solve Manning using bedslope = 0.005 ft/ft.

Solve Manning's Equation for these flows and record the flow depth

Transect	Subreach	Average Depth (ft) (124 cfs)	2-yr Depth (1,880 cfs)	Increase in Depth (ft)
70	3-8	1.0	5.2	4.2
90	3-9	2.6	7.6	5.0
104	3-10	2.9	8.5	5.6
110	4-1	2.7	8.7	6.0
122	4-2	2.7	8.9	6.2
134	4-3	1.6	7.3	5.7
160	4-4B	1.3	6.4	5.1
170	4-5A	1.4	6.9	5.5
180	4-5A	2.7	7.4	4.7
198	4-6	1.6	7.4	5.8
206	4-6	2.0	7.4	5.4
			Average =	5.4